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Dynamic Economic Dispatch Assessment Using Particle Swarm Optimization Technique

Muhammad Murtadha Othman[1], Mohd Affendi Ismail Salim[2], Ismail Musirin[3], Nur Ashida Salim[4], Mohammad Lutfi Othman[5]
[1,2,3,4]Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[5]Centre for Advanced Power and Energy Research and Department of Electrical and Electronics Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

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ABSTRACT

This paper presents the application of Particle Swarm Optimization (PSO) technique for solving the Dynamic Economic Dispatch (DED) problem. The DED is one of the main functions in power system planning in order to obtain optimum power system operation and control. It determines the optimal operation of generating units at every predicted load demands over a certain period of time. The optimum operation of generating units is obtained by referring to the minimum total generation cost while the system is operating within its limits. The DED based PSO technique is tested on a 9-bus system containing of three generator bus, six load bus and twelve transmission lines.

Corresponding Author:

Muhammad Murtadha Othman,
Faculty of Electrical Engineering,
Universiti Teknologi MARA,
40450 Shah Alam, Selangor, Malaysia.
Email: mamat505my@yahoo.com

1. INTRODUCTION

DED is used to determine the optimal schedule of generating outputs on-line so as to meet the load demand at the minimum operating cost under various system and operating constraints over the entire dispatch periods. DED is an extension of the conventional economic dispatch problem that takes into consideration the limits on the ramp rate of generating units to maintain the life of generation equipment. The ramp rate constraints distinguish the DED problem from the traditional, static Economic Dispatch (ED) [1],[2]. In general, the DED is solved by discretization of the entire dispatch period into a number of small time periods.

Therefore, the static economic dispatch in each dispatch period is solved subject to the power balance constraints and generator operating limits. Previous efforts on solving static ED problems have employed various mathematical programming methods and optimization techniques. These conventional methods include the lambda-iteration method, the base point and participation factors method, the gradient method and dynamic programming (DP) [3].

Unfortunately, for generating units with non-linear characteristics, such as prohibited operating zones, ramp rate limits, and non-convex cost functions, the conventional methods can hardly to obtain the optimal solution. Furthermore, for a large-scale mixed-generating system, the conventional method has oscillatory problem resulting in a local minimum solution or a longer solution time [4].

In order to make numerical methods more convenient in solving non-convex DED problems, artificial intelligent techniques, such as the gradient-type Hopfield neural networks, have been employed to

solve DED problems for units with ramping rate limit and spinning reserve constraint [5]. However, an unsuitable transfer function adopted in the Hopfield model may suffer from excessive numerical iterations, resulting in huge calculations [6].

In the past decade, the global optimization techniques known as genetic algorithms (GA), simulated annealing (SA), tabu search (TS), and evolutionary programming (EP), which are the forms of probabilistic heuristic algorithm, have been successfully used to overcome the non-convexity problems of the constrained ED [7],[8]. The GA method has usually better efficiency than the SA method because the GA has parallel search techniques, which emulate natural genetic operations. Due to its high potential for global optimization, GA has received great attention in solving DED problems.

Therefore, PSO based economic dispatch algorithm has been reported and it has been shown that the algorithm is capable of finding the global or near global optimum solutions for large optimization problems. This paper presents an application of PSO technique to solve the DED problem in a power system. A 9 bus system containing of three generator bus, six load bus and twelve transmission lines is used as case study to show the effectiveness of the PSO technique over DED. The DED is determined by referring to the best minimum of total generation cost. The best minimum of total generation cost is determined by gbest value produced from PSO.

2. DED METHODOLOGY

The objective function of dynamic economic dispatch (DED) is to schedule the outputs economically over a certain period of time under various system and operational constraints. The problem is formulated as follows:

$$F_t = \sum_{t=1}^{T}\sum_{i=1}^{N} F_{it}(P_{it}) \qquad (1)$$

where; *Ft*: total operating cost over the whole dispatch period.

T: number of hours in the time horizon.

N: number generating units.

Fit (*Pit*): fuel cost in terms of its real power output, P_{it} , at time, *t*.

The thermal plant can be expressed as input-output models where the input is the electric power output of each unit and the output is the fuel cost. The quadratic fuel cost function is given as follows:

$$F_{it}(P_{it}) = a_i + b_i P_{it} + c_i P_{it}^2 \qquad (2)$$

where; a_i , b_i, c_i : fuel cost coefficients of the i^{th} generator.

The objective function of DED is acquired by fulfilling the equality constraint of real power balance and inequality constraint of real power operating given in Equations 3 and 4, respectively.

$$\sum_{i=1}^{N} P_{it} = P_{Dt} + P_{Lt} \qquad (3)$$

where; P_{Dt} : forecasted total power demand at time, *t*.

P_{Lt} : transmission loss at time, *t*.

$$P_{it\,\min} \leq P_{it} \leq P_{it\,\max} \qquad (4)$$

where; $P_{it\,\min}$: minimum real power output of generator *i* that can supply at time, *t*.

$P_{it\,\max}$: maximum real power output of generator *i* that can supply at time, *t*.

2.1. Representation of Particle Positions

In an initial process of PSO that is *k*=1 the positions or components (generating units) for each particle is randomly initialized within the feasible range such a way that it should satisfy the constraint given by Equation 4. In every j^{th} particle ($X_{j,t}$), there are *N*, total number of generators at every time interval, *t*. The arrangement of generator's components or positions for each particle, *j*, is shown in Equation 5.

$$X_j = \begin{pmatrix} S_{11} & S_{12} & \cdots & S_{1T} \\ S_{21} & S_{22} & \cdots & S_{2T} \\ \vdots & \vdots & \ddots & \vdots \\ S_{N1} & S_{N2} & \cdots & S_{NT} \end{pmatrix} \tag{5}$$

where; $P_{it} = S_{it}$: component or position of a particle, which is the real power output of, i^{th}, generating unit at time interval, *t*.

j : number of particles.

The best particle, X_j , is selected which gives a minimum value of generation cost function given by Equation 1. This shows that the best, X_j , is referred to as, *gbest*, of all particles in the current iteration.

2.2. PSO Technique

Kennedy et al. [9]-[11] has mentioned that the PSO is basically developed through simulation of bird flocking in two-dimension space. The position of each particle is represented by XY co-ordinate. The velocity is expressed by *Vx* (the velocity of X axis) and *Vy* (the velocity of Y axis). Modification of the particle position is realized by position and velocity information. Bird flocking optimizes a certain objective function. Each particle knows its best value so far (*pbest*) and its XY position. This information is analogous to personal experiences of each particle. Moreover, each particle knows the best value so far in the group (*gbest*) among *pbests*. This information is analogous to knowledge of how the other agents around them have performed. Now, each agent tries to modify its position using the information, such as, the current positions (x, y), the current velocities (*Vx*,*Vy*), the distance between the current position and pbest*i* and the distance between the current position and *gbest*. These modifications can be represented by the concept of velocity. Velocity of each particle can be modified by the following equation:

$$V_i^{k+1} = wV_i^k + c_1 rand_1 (pbest_i - S_i^k) + c_2 rand_2 (gbest - S_i^k) \tag{6}$$

The following weighting function usually utilized in Equation 1.

$$w = w_{\max} - \left[\frac{(w_{\max} - w_{\min})}{iter_{\max}} \right] iter \tag{7}$$

where; $w_{\max}$: maximum inertia weight

$w_{\min}$: minimum inertia weight

$iter_{\max}$: maximum iteration number

$iter$: current iteration number

Using the Equation 7, a certain velocity, which gradually gets close to *pbest* and *gbest* can be calculated. The current position (searching point in the solution space) can be modified by the following equation.

$$S_i^{k+1} = S_i^k + V_i^{k+1} \tag{8}$$

where; V_i^k : velocity of particle *j* at iteration *k*.

V_i^{k+1} : velocity of particle *j* at iteration *k+1*.

w: inertia weight factor.

c_1 : constant weighting factor related to *pbest*.

c_2 : constant weighting factor related to *gbest*.

$rand_1$: random number between 0 and 1.

$rand_2$: random number between 0 and 1.

S_i^k : current position of particle *j* at iteration *k*.

S_i^{k+1} : current position of particle *j* at iteration *k+1*.

$pbest_i$: best position of particle *j*.

gbest : best particle.

The basic procedure of PSO is presented in term of flow chart shown in Figure 1.

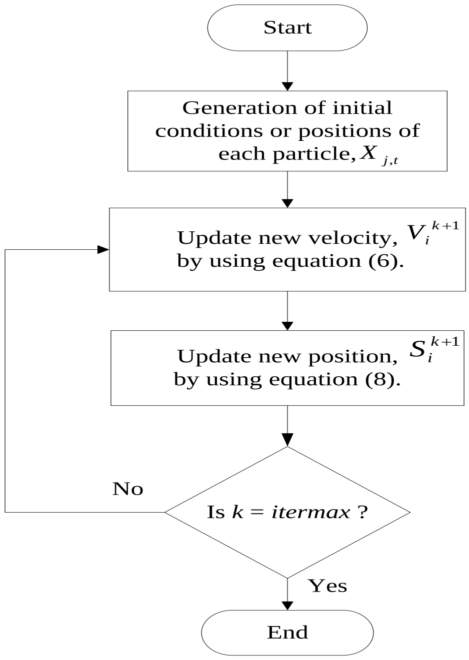

Figure 1. Flowchart of PSO procedure

2.3. DED based PSO Technique

The procedures of PSO technique that used for solving the DED for every time interval are explained as follows:

a. Initialize the particle, X_j and velocity, V_i. The velocity, V_i should be in the range of [*Vmax,Vmin*] and each particle should satisfy the constraint given by Equation 4.
b. Calculate the generation fuel cost $F(S_i)$ for each position or generator, S_i in every particle, *j*.
c. Obtain the *pbest* for every generator which refers to the minimum generation fuel cost.
d. Obtain the *gbest* which refers to a particle with minimum amount of total fuel cost.
e. Update V_i by using Equation 6. If $V_i < V_{i\min}$ then, $V_i = V_{i\min}$. On the other hand, if $V_i > V_{i\max}$ then, $V_i = V_{i\max}$.
f. Update S_{it} for every particle by using Equation 8. Check whether each generator's output is within its operating limit. If $S_i < S_{i\min}$ then, $S_i = S_{i\min}$. Besides that, if $S_i > S_{i\max}$ then, $S_i = S_{i\max}$.
g. Go to the next time interval, *t*. Repeat procedure b) – f) until *t*=*T*.
h. Repeat procedure b) – g) until *k*=*itermax*.
i. Record the $S_{i,t}$ which refers to *gbest*.

The procedures of PSO technique that used for solving the DED for every time interval are presented in term of flow chart shown in Figure 2.

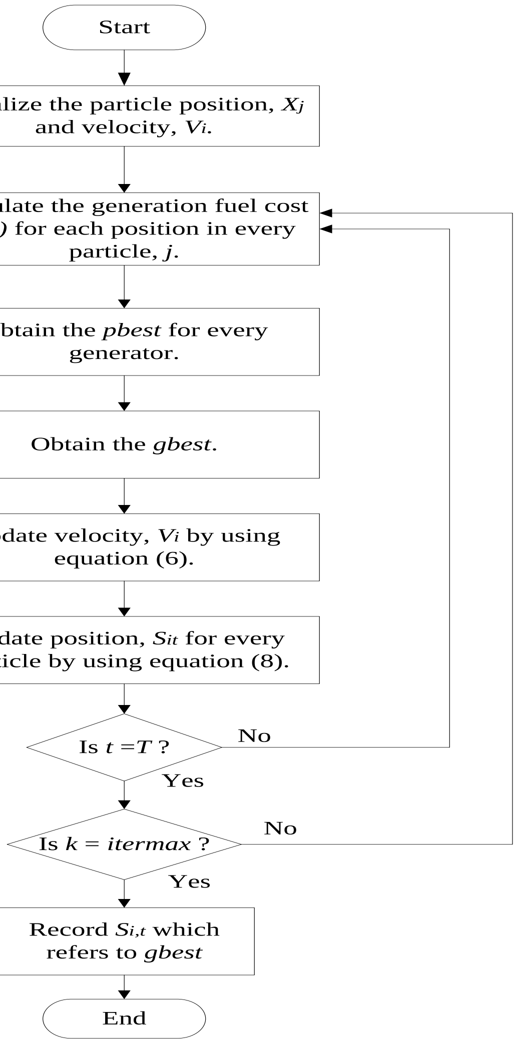

Figure 2. Flowchart of dynamic economic dispatch (DED) based particle swarm optimizaton (PCO) technique

3. RESULTS AND DISCUSSION

A 9 bus system is used to demonstrate the performance of PSO to determine the DED of each generator at every time interval [12]. The system consists of 3 units of generator, 6 load bus and 12 transmission lines. The load demand for the time intervals of 24 hours is given in Table 2. The information for every generating unit is given in Table 1.

The simulation results of DED based PSO is obtained from a PC with Pentium 4 2.8 GHz processor and 512MB RAM memory. The DED based PSO algorithm is written in MATLAB programming language. The parameters which is used in the PSO is given in Table 3.

Table 1. Generator Unit Data

Quantities	Unit 1	Unit 2	Unit 3
ai (\$/h)	240	220	240
bi (\$/MWh)	6.7	6.1	6.5
ci ($\$/MW^2 h$)	0.009	0.005	0.008
Pimin (MW)	50	50	50
Pimax (MW)	200	200	100

Table 2. Load Demand for 24 Hours

Time (h)	Load (MW)	Time (h)	Load (MW)
1	185	13	263
2	174	14	263
3	166	15	257
4	163	16	260
5	163	17	274
6	166	18	277
7	205	19	277
8	238	20	266
9	263	21	252
10	266	22	230
11	266	23	202
12	263	24	174

Table 3. PSO Parameters

Particle, *m*	3
Maximum iteration, *itermax*	300
Maximum velocity, *Vmax*	20
Minimum velocity, *Vmin*	-20
Maximum inertia weight, *Wmax*	0.9
Minimum inertia weight, *Wmin*	0.4
c_1	1.4
c_2	1.4

The MW for every generating unit is represented by P_1, P_2 and P_3. The MW optimal generating units for every time interval are given in Table 4. As shown in the Table 4, the optimal total cost function for one day is $61,024. Maximum of the optimal total cost function has been recorded at 3rd hour that is $3461.4. Besides that, minimum of the optimal total cost function has been recorded at 21st hour that is $1868.8. The MW optimal generating unit for each hour satisfies the system constraint which is given by Equation 4.

Table 4. MW Optimal Generating Unit for 24 Hours

Number of hour	P_1 (MW)	P_2 (MW)	P_3 (MW)	Cost ($/h), $F_{it}(P_{it})$
1	56.4611	176.0581	87.9029	2644.8
2	60.5929	113.5555	76.8837	2124.5
3	188.0138	54.1272	80.3242	3461.4
4	77.7955	168.3587	60.0683	2880
5	77.8623	120.4124	60.8799	2860.8
6	124.6537	126.6526	73.4685	2254
7	138.3174	141.0948	77.6490	2659
8	85.6192	180.0280	51.1691	3097.9
9	149.6275	80.0374	74.0888	2096.9
10	60.0764	144.8219	78.6349	2205.9
11	98.8939	170.5141	68.0518	2413.6
12	99.0865	122.2892	67.1286	2818
13	84.7880	116.2985	73.5884	2382.4
14	56.2278	148.8529	50.0000	3052.3
15	171.0245	88.2155	77.7500	2342.2
16	59.4741	115.6919	66.7755	2330.5
17	72.7171	80.2540	66.8461	2792.3
18	50.0000	147.4034	72.7955	2836.2
19	75.9820	138.0081	69.0557	2066.7
20	63.3240	100.6265	60.3924	2429.1
21	102.2622	135.2888	75.8194	1868.8
22	113.4904	92.6163	95.5837	1903.4
23	69.0953	103.0837	74.0524	2573.5
24	93.8275	141.8791	77.7489	2930.1
	Total Cost ($/h), *Ft*			61,024

Table 5. Computing Time and Total Generation Cost

Technique	Total Generation Cost ($/h)	Computing Time (s)
PSO	61,024.00	37.12

4. CONCLUSION

Dynamic economic dispatch is a complex optimization problem whose importance may increase as competition in power generation intensifies. The DED planning must perform the optimal generation dispatch among the operating units to satisfy the system load demand, spinning reserve capacity, and practical operation constraints of generators. PSO is a recent tool for solving complex optimization problems, being attracted by the researchers in various diverse fields. It was also effectively used in solving complex problems in the power system field. It is faster in finding quality solution compared to any evolutionary computation technique but finds it difficult while exploring complex functions. It leads to premature convergence and also has a poor fine tuning of the final solution. The PSO algorithm has been demonstrated to have superior features, including high-quality solution and good computation efficiency. The results showed that the proposed PSO method was indeed capable of obtaining higher quality solution efficiently in constrained DED problems.

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